Cross-Exercise on Quadriceps Deficit after ACL Reconstruction

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Abstract

A few studies concerning the improvement of quadriceps muscle strength deficit (QD) at an early stage following anterior cruciate ligament (ACL) reconstruction have been conducted whereas, ACL rehabilitation protocols based on contralateral quadriceps strength (QS) do not exist. Given these, the goals of our study were (1) to evaluate the effects of cross-eccentric exercise (CEE) on QD on ACL reconstructed knees, and (2) to explore any changes in QD following CEE provided at the frequencies of 3 or 5 times per week. For this study, 42 ACL-reconstructed patients were randomly assigned into 3 groups, two experimental and one control and followed an 8-week rehabilitation program. Additionally, the experimental groups received CEE for 3 and 5 days per week for 8 weeks in their uninjured knees. QS was evaluated with an isokinetic/isometric test, at 60 degrees of knee flexion of both limbs before and after completion of CEE. Two-factor ANOVA showed a significant improvement of QD between groups ($F = 5.16$, $p = 0.01$) after CEE completion on ACL reconstructed knees. Statistically significant results arose from the 3 days per week ($D = 18.60$, $p = 0.01$) and 5 days per week ($D = 15.12$, $p = 0.04$) experimental groups, whereas the control group did not yield any statistically significant differences. CEE used as an adjunct to the ACL traditional rehabilitation program at the weekly frequencies of 3 and 5 times at the early stage of reconstruction significantly improved QD.

Keywords
- cross-education
- bilateral training
- quadriceps deficit
- eccentric exercise
- anterior cruciate ligament

Following anterior cruciate ligament (ACL) surgery significant quadriceps muscle strength deficit (QD) usually for up to 20% compared with the uninjured knee in the first 4 weeks has been reported.[1–4] And, preoperative quadriceps strength (QS) has been found as one of the important predictors for knee function for as long as 2 years after ACL reconstruction.[5–7] However, so far, there is no agreement as to what is the ideal treatment for postoperative quadriceps weakness for individuals after ACL reconstruction.

Quadriceps muscle activity causes anterior tibia translation between 20 and 60 degrees of knee flexion[8,9] and this is closely related to the increased ACL strain levels at these angles.[10–12] Thus, the fact that QD is greater at the knee range of 60 degrees[10–13] following ACL reconstruction, might be attributed to the interrelation between quadriceps activity and ACL strain levels following the operation graft technique. These findings seem to justify the specific focus of the exercise rehabilitation program at 60 degrees of motion, in the early

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stage after ACL reconstruction.[10–13] As a consequence, for ACL-reconstructed patients an optimizing postoperative rehabilitation program for alleviating QD, through the safest and most expeditious means available is recommendable. Such a safe, practical, economic, and potentially beneficial form of exercise is contralateral or cross-exercise (CE).

CE focus on exercising the contralateral limb to increase the strength in the homologous muscle on the untrained limb, without directly involving the latter in the motor activity.[14] CE is a safe form of exercise, because exercise of one limb can produce a beneficial effect in the contralateral limb for patients who have conditions that prevent them from exercising a limb.[14]

However, the clinical significance of this intervention has not been critically evaluated for special population groups such as, postoperative patients versus unexercised control groups.

Thus, it is not unreasonable to assume that cross-eccentric exercise (CEE) applied at a higher than 3 days per week frequency (such as 5 days) as an adjunct to the traditional ACL rehabilitation program may improve QD at 60 degrees on ACL-reconstructed knee in the early ACL-postoperative stage.

The goals of our study were to explore (1) the effects of an 8-week CEE program on QD at 60 degrees of flexion on ACL-reconstructed knees and (2) any changes in QD when applying CEE for 3 or 5 times per week in the early stage of ACL reconstruction.

Methods

This study received ethical approval from the Committee of Laboratory for Research of Musculoskeletal system at the University of Athens.

Sample

Participants consisted of male patient soldiers in the Greek army referred from the outpatient Orthopaedic and Physical Therapy department of General Army Hospital 401 (GAH 401) in Athens, with unilateral ACL ruptures confirmed by both magnetic resonance and clinical examination performed by the same orthopedic surgeon.

Out of the 58 patients initially assessed, 42 met the inclusion criteria for eligibility in the study, and were randomly assigned (by flip coin) into one of three groups, two experimental ones (Groups A and B) and one control (Group C).

Our sampling selection is included in stratified random sampling. A power analysis performed before the study and 14 subjects comprised each one of the three groups. Patients' characteristics and admission profiles are illustrated in ►**Table 1**.

To be considered eligible for inclusion patients had to: (1) be between 20 and 25 years of age, (2) have a complete rupture of ACL within the past 40 days to 6 months (subacute phase of ACL injury)[15,16] with no other recent or previous injuries that demanded surgical reconstruction, (3) have at least 3 mm of bilateral difference in anterior knee joint laxity, as measured by KT1000 knee arthrometer (MEDmetric, San Diego, CA), (4) be between levels C and D in the objective part of 2000 International Knee Documentation Committee[17] knee examination form (surgical part), indicating abnormal or severely abnormal knee function, and (5) score between 0 and 5 in activity levels in recreational or sports activities as assessed by Tegner activity score questionnaire (►**Table 1**).[18]

Patients were excluded if they had clinical varus/valgus laxity or symptomatic meniscal injuries, painful knee active range of motion, joint swelling, leg length discrepancy, cartilage lesions affecting the subchondral bone, fractures, and a history of lower extremity pain in the last 6 months that did not agree with the ACL-rehabilitation requirements.

An arthroscopically assisted autograft technique was used by the same surgeon, using the semitendinosus and gracilis tendons in quadrapted fashion as a graft source.[19] Before inclusion, all patients signed a written informed consent form.

Outcome Measure

All patients were evaluated in two phases; 1 week preoperatively and 9 weeks postoperatively.

QS was tested with isokinetic dynamometer (Kin Com AT^{+}, Chattanooga Group Inc., Chattanooga, TN) by performing three maximum isometric contractions of 5 seconds each at 60 degrees of knee flexion at each knee. Patients performed four repetitions as a practice trial before testing. The uninjured knee was tested first and was followed by the ACL-injured one. Visual and verbal encouragement was provided. Isokinetic peak torque values were measured in Newton meters (Nm) for both limbs at 60-degree knee flexion angle.

Leg dominance was assessed on the basis of a questionnaire consisting of six questions specifically selected from the literature as highly reliable.[20,21] Of the 42 participants, 12 were left-leg dominant, 8 had equally dominant sides, and 22 were right-leg dominant (►**Table 1**).

ACL Rehabilitation Program

All subjects commenced the ACL rehabilitation program 1 week following reconstruction at a 5-day weekly frequency (Monday to Friday) for 8 weeks.

All subjects received the same ACL rehabilitation program, which was divided into two subsequent phases; the progressive 8-week program corresponded to phase 2 according to Wilk et al[22] and Majima et al[23] rehabilitation principles (►**Table 2**).

The 8-week time interval for rehabilitation was considered appropriate and adequate for resolving knee impairments (swelling pain), range of motion deficits, restoring muscle strength, and neuromuscular responses. Additionally, the 8-week duration is related to the graft vascularization phase[24–26] as well as specific biochemical, mitochondrial, and neurological muscular adaptations to take place.[1,3]

Consequently, we hypothesized that this duration could be critical in establishing a strength stimulus on QD after ACL reconstruction. The program was delivered by two highly experienced musculoskeletal physical therapists of the Physiotherapy Department of 401 GAH (mean musculoskeletal experience: 5 years).

Table 1 Subjects' Characteristics and Admission Criteria (Mean ± SD)

Subjects Characteristics	Group A (3 d/wk) ($n = 14$)	Group B (5 d/wk) ($n = 14$)	Group C (Control) ($n = 14$)
Age (y)	23.64 ± 2.56	25.07 ± 2.40	23.14 ± 2.71
Weight (kg)	81.28 ± 8.40	82.50 ± 9.83	75.00 ± 8
Height (cm)	179.07 ± 5.18	182.21 ± 4.70	175.85 ± 5.78
BMI (kg/m^2)	24.80 ± 2.20	25.24 ± 2.90	25.80 ± 4.73
Time of ACL injury (months)	4.42 ± 1.79	4.42 ± 1.75	3.67 ± 1.78
SD (KT-1000)[a] (mm)	5.57 ± 2.40	6.35 ± 1.21	5.92 ± 2.12
Tegner activity score (0–10)	3.07 ± 1.32	3.28 ± 1.32	2.92 ± 1.43
Right-leg dominant($n = 22$)[b]	$n = 7$ (2.94%)	$n = 7$ (2.94%)	$n = 8$ (3.36%)
Left-leg dominant($n = 8$)[b]	$n = 3$ (1.26%)	$n = 2$ (0.84%)	$n = 3$ (1.26%)
Equally dominant legs ($n = 12$)[b]	$n = 4$ (1.68%)	$n = 5$ (2.1%)	$n = 3$ (1.26%)

[a]Side-to-side difference: (SD) of tibia anterior translation on the injured side in millimeter.
[b]Leg dominance and percentage of dominant and non-dominant legs in each of the three groups.
ACL, anterior cruciate ligament; BMI, body mass index; SD, standard deviation.

Prior to the commencement of the study the principal investigator adequately trained the two involved therapists to standardize their rehabilitation procedure.

All patients were instructed to wear their functional brace and use crutches for 6 weeks during their daily activities To ensure that all patients received similar amounts of exercise, a home exercise program was not given.

After completion of the 8 weeks of ACL rehabilitation program, patients had to meet the following criteria: no pain (as indicated with a 10-cm visual analog scale), no effusion (as measured by joint circumference), walking independently, 0- to 100–120-degree knee motion, straight leg raising in all planes, low resistance (10 reps), and multiple reps (20) with no extension lag and mini-squats 0 to 100 degrees.

CEE

The CEE program was designed based on previous studies,[27–29] as specific evidence-based guidelines for CEE on quadriceps in the early stage after ACL-reconstructed stage

Table 2 ACL Postoperative Rehabilitation Program[22,23]

Postoperative Phase	Rehabilitation Regimen
Phase 1; Duration 2–4 wk	• Immediate straight leg raising • Early range of motion exercise with an emphasis on gaining full knee extension (0 degrees) • Weight-bearing full as tolerated • First week 70-degree flexion • Static squat (90-degree flexion)
Phase 2; Duration 2–3 mo	• Endurance training (biking) • Progressive resistance training (leg press, calf press, step up) • Dynamic squat (0–110 degrees) • Balance exercises • Eccentric muscle contractions • Progressive resistance exercise full range of motion, hop on one leg without pain • Isokinetic exercise and assessment
Phase 3; Duration 3–6 mo	• Continued progressive resistance and endurance training • Jogging/running, swimming • Eccentric training (active lengthening force production, such as jumping exercises) • Strengthening and functional exercise training to prepare the individual for full return activity • Criteria for returning to full activity: • 80% strength and 85% functional ability, proprioception >90% • Extension/flexion strength difference >70% compared with the nonsurgical lower extremity and Lysholm knee score >90
Functional brace	6 wk

Table 3 Quadriceps Strength (QS) Changes (Pre- and Postoperatively) Across the Groups

Groups	↑ QS% Uninjured Knee[a]	↓ QS% Injured Knee[b]
	Mean ± SD	
Group A (3 d/wk)	↑ 22.70 ± 20.60	↓ 16.25 ± 24.70
Group B (5 d/wk)	↑ 18.00 ± 17.60	↓ 6.30 ± 26.01
Group C (control)	↑ 14.08 ± 16.20	↓ 37.83 ± 16.90

[a]↑ QS%, an increase of percentage in quadriceps strength.
[b]↓ QS%, a decrease of percentage in quadriceps strength.
QS, quadriceps strength; QS%, percentage quadriceps strength; SD, standard deviation.

do not exist. Cross-training was an eccentric exercise program applied on quadriceps' uninjured knee which started concurrently with the ACL physiotherapy program.

The basic exercise was one repetition maximum (1 RM) of eccentric contraction (knee extension to flexion) on the isotonic (concentric/eccentric) leg extension machine, whereas resistance was placed just above the medial malleolus.[27,30]

The intensity of the eccentric exercise program was submaximal 80% of 1 RM, because it has been reported to have greater strength adaptations than maximal ones.[27,31–33] So, the resistance used ranged from 60.85 ± 13.93 kg for the first and 61.50 ± 11.40 kg for the second experimental group.

The CEE consisted of two warm up sets with no loads, following by five sets of six repetitions at 80% of 1 RM with two minutes of rest between sets.[27,29,30]

The first experimental group (Group A) undertook the CEE at a frequency of 3 days per week (E1–3d/w), the second experimental group (Group B) at 5 days per week (E2–5d/w), whereas the control group (Group C) undertook only the ACL rehabilitation program.

The CEE program and the intensity were standardized throughout the 8-week period to monitor all patients, and facilitate clinical applicability of the procedure.

Data Analysis

Mean values and standard deviations were calculated for the isometric QS profile for each knee across the three groups.

One-way ANOVA was used for calculating any QS changes percentage from pre- to posttest for both, the injured and uninjured knees (pre- minus posttest/100) separately across the three groups. Post hoc analysis based on Scheffe criterion was applied to determine the location of group differences.

Two-factor ANOVA (group × time) was applied to test for group differences in QD percentage ([preoperative QS: injured – uninjured] – [postoperative QS: injured – uninjured] /100); where the group factor had three levels (Groups A, B, and C), and the time factor had two levels (pre- and postoperatively).

Body mass was used as a covariate in the analysis, as there were differences in the body weight between groups. Post hoc analysis based on Tukey HSD criterion was applied to determine the location of group differences of QD on ACL-reconstructed knees after CEE application. Results were considered statistically significant if p values were less than 0.05. All data were analyzed using SPSS software (IBM Software, Armonk, NY).

Results

QS changes from preoperatively up to 8 weeks postoperatively across the groups are shown in ►**Table 3**. An increase of QS was evident for the uninjured knees across the groups postoperatively, in contrast to the injured knees, which demonstrated a decrease in QS for all groups (postoperatively).

Quadriceps absolute strength and percentage changes in QD between the injured and uninjured knees for the groups are shown in ►**Tables 4** and **5**.

Changes in postoperative QD between knees were for the first experimental group (Group A) from 12.17 to 27.95%, for the second (Group B) from 17.22 to 29.82%, and for the control group from 24.32 to 53.00% (►**Table 5**).

One-way ANOVA showed that there was no significant interaction effect on QS scores in uninjured knees between the groups ($F = 0.781$, $p > 0.05$) when eccentric exercise program was conducted.

Table 4 Quadriceps Absolute Strength and Changes in QD% between Knees Preoperatively

Groups	QS Uninjured	QS Injured	QD% Uninjured-Injured
	Mean ± SD		
Group A (3 d/wk)	437.40 ± 178.54	420.64 ± 84.74	12.17 ± 9.30[a]
Group B (5 d/wk)	371.35 ± 93.50	315.31 ± 91.00	17.22 ± 15.45[a]
Group C (control)	418.90 ± 112.10	354.05 ± 127.50	24.32 ± 17.95

[a]Significantly less than the control group ($p < 0.05$).
QD%, percentage quadriceps muscle strength deficit; QS, quadriceps strength; SD, standard deviation.

Table 5 Quadriceps Absolute Strength and Changes in QD% between Knees, at 8 Weeks Postoperatively

Groups	QS Uninjured	QS Injured	QD% Uninjured-Injured
	Mean ± SD		
Group A (3 d/wk)	458.75 ± 87.33	344.80 ± 135.23	27.95 ± 24.20[a]
Group B (5 d/wk)	394.00 ± 91.20	295.50 ± 84.80	29.82 ± 21.05[a]
Group C (control)	487.95 ± 108.33	225.30 ± 122.30	53.00 ± 24.20

[a]Significantly less than the control group ($p < 0.05$).
QD%, percentage quadriceps muscle strength deficit; QS, quadriceps strength; SD, standard deviation.

However, for the injured knees, a significant interaction effect on QS scores was evident among the groups (F = 6.95, $p < 0.05$) following CEE. In particular, post hoc analysis determined that the significant results arose from the first experimental group compared with the control (D = 21.60, $p = 0.04$), and from the second one compared with the control one (D = 31.60, $p < 0.001$) (►**Fig. 1**).

Two-factor ANOVA showed that there was a significant interaction effect on QD percentage between groups and time (F = 5.16, $p < 0.001$) after the 8-week CEE program, on the reconstructed knees. Post hoc analysis by Tukey HSD determined that the significant results arose from both experimental groups compared with the control one (Group A: D = 18.60, $p = 0.01$; Group B: D = 15.12, $p = 0.04$), (►**Fig. 2**).

The covariate body mass did not have a confounding effect on the groups' results in the research procedure (F = 0.00, $p = 0.97$, $p > 0.05$).

Discussion

The purposes of this study were to investigate whether 8 weeks of a CEE program could offer more improvement or minimize quadriceps muscle strength deficit at 60 degrees of knee flexion, by either being applied at 3 or 5 times per week, in the early postoperative stage of ACL reconstruction.

The results of this study revealed changes in both knees: a strength increase of 14 to 22% for the uninjured knees across the groups, and a decrease of 6 to 16% for the two experimental groups and 37% for the control one for the injured ones; 8 weeks following the ACL reconstruction (►**Table 3**).

Evaluation of QD showed changes in percent from 12 to 24% to 27 to 53% from preoperatively to 8 weeks postoperatively for the three groups (►**Table 5**). Our QD values, irrespective of the supplementary CEE program performed, emphasizes that patients with ACL reconstruction in the early stage of rehabilitation showed particular interesting changes in QS from pre- to posttest. These results are confirmed by previous findings, where postoperative QDs have been found between 10 and 20%,[1,3,6,7,34,35] despite the plethora of the progressive and accelerated exercise programs, for ACL-reconstructed patients, long-term impairments often persists.[3,7,34,35]

The corresponding QS values for the uninjured knee entailed increases, it would appear logical that 8 weeks of eccentric exercise program on a healthy trained limb have potential improvement. On the other hand, the status of the uninjured side may lead to misinterpretation of results due to possible bilateral neuromuscular changes after injury.

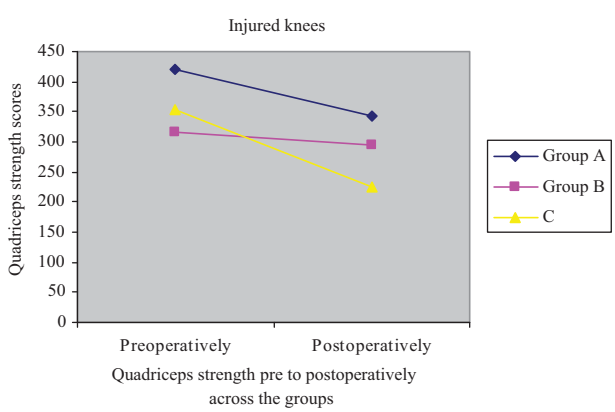

Figure 1 A significant interaction effect of contralateral-eccentric exercise (CEE) on quadriceps strength (QS) arose from Group A (3 d/wk) and Group B (5 d/wk) compared with the control one, at 8 weeks postoperatively.

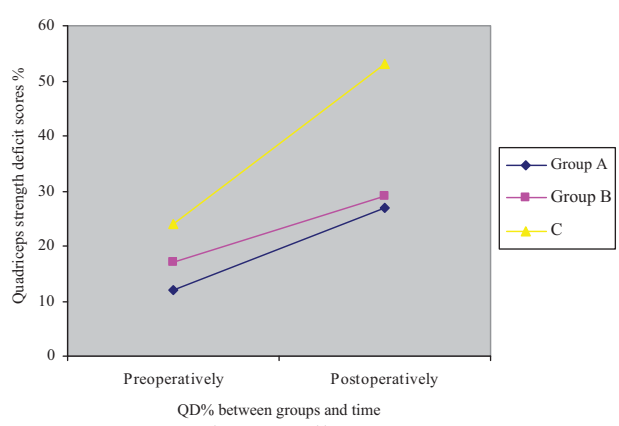

Figure 2 A significant interaction effect of CEE on quadriceps changes in quadriceps deficit (QD) percentage arose from Group A (3 d/wk) and Group B (5 d/wk) compared with the control one, at 8 weeks postoperatively.

The results confirmed our first hypothesis that adding CEE to the traditional ACL rehabilitation program would lead to significant improvements of QD at 60 degrees of flexion in ACL-reconstructed patients. This was evident for subjects classified in experimental groups, received CEE 3 or 5 days per week. Both experimental groups showed a significantly less quadriceps muscle strength deficit compared with the control one, 8 weeks after the ACL postoperative rehabilitation phase (►**Table 5**).

This improvement on QD could be attributed to cross eccentric exercise. As far as the type of CE is concerned, eccentric exercise has been found to be superior to isometric or concentric exercise and seems to have the greatest effect on QS accounting for the greater increases in eccentric and isometric forces.[31–33,36–39]

As a consequence, our results emphasize that patients with ACL reconstruction, in the early stage of rehabilitation, have potential for clinically relevant QS improvement at 60-degree knee flexion when CEE is conducted as a supplement to the ACL traditional rehabilitation program.

ACL postoperative quadriceps muscle strength deficit have not previously been assessed using CE as supplementary exercise program to the traditional rehabilitation one. Limited studies have been reported on the effect of CE on patient population. It has been reported that CEE improves quadriceps muscle strength at 45- and 90-degree knee angles and quadriceps accelerated reaction time at 90 degrees of knee flexion on the ACL-reconstructed knee in the early rehabilitation stage; 8 weeks following the reconstruction.[40,41] Arai et al[42] investigated, in six orthopedic patients, the effect of CE on QS by applying a proprioceptive neuromuscular facilitation (PNF) exercise, at various knee angles. The PNF-CE was significantly effective on QS at 60 degrees of knee flexion.

The limited amount of information for QD following CE in the early stage of ACL reconstruction should be addressed in future studies.

The second purpose of this study explored the most effective CEE frequency between the frequencies of 3 and 5 days per week (experimental groups) for the improvement of QD on the ACL-reconstructed knees.

The decision on the above frequencies was based on the notion that any exercise program must be performed for a sufficient duration of weeks and days per week to allow the muscle-specific biochemical, mitochondrial, and neurological adaptations to reach a steady state (more than 4 to 5 weeks, 3 to 5 days per week).[43,44]

Our 8-week CEE program combined with the ACL traditional rehabilitation program statistically minimized QD in both experimental groups compared with the control one. The results confirm previous findings that quadriceps improvements were greater for ACL-reconstructed patients who followed 3 days per week CEE rather than the control one.[40,41]

However, in our study no statistical results were found between the two experimental groups. From rehabilitation perspective this would appear logical that a supplementary exercise program attached to the classic rehabilitation program is more effective and is more likely to minimize QD, compared with a rehabilitation one performed alone. Whereas, no reports have implicated that a particular frequency of exercise has the greatest amount of CEE benefits on QD.

Several different training protocols designed to explore CE gains and adaptations comparing different kinds of exercise programs (isometric, eccentric, concentric, etc.) have been limited to the training frequency of 3 days per week.[14,27,33,36–39] All the above studies used a 4- to 12-week training program and only a limited number of studies have explored CE in patients following ACL reconstruction.[40,41] Nevertheless, further research should explore different exercise frequencies in CE for this patient population.

From our findings it can be stated that it is possible to achieve significant and clinically important improvements in QD adding the CE as an adjunct rehabilitation program to the traditional ACL one, at the early phase of reconstruction.

A crucial issue when introducing progressive exercise therapy programs is the tolerance for the training load through a neural mechanism which produces the earliest activation of central nervous system. As far as the mechanism of action of CE is concerned, it is believed to be mediated by neural mechanisms including diffusion of impulses between hemispheres, coactivation via bilateral corticospinal pathways, postural stabilization, and the cerebral cortex theory.[14] This latter theory has been referred to as the most dominant mechanism acting via the voluntary contraction of a specific muscle—on the trained side—and then a facilitation effect is produced at the same motor point in the opposite side via the cerebral cortex.[28,29,45]

Future randomized controlled trials including treatment groups with larger sample sizes testing different frequencies of CE programs are needed to verify the potential effectiveness of this proposed program.

Limitations

Although, an assessment of which was the dominant limb was provided, due to the study design and to our small sample we did not determine the effectiveness of CEE after the ACL reconstruction for the dominant and nondominant limbs. Future studies are needed to clarify this issue.

During the 8 weeks of CEE we did not monitor the training velocity between the two experimental groups, and did not change the mode of the program. On the other hand, it does not seem to be an obvious relationship across studies between the mode of exercise program (training velocity, intensity, duration) and the magnitude of CE.[14]

However, the training procedures employed in the study supported a clinically applicable and practical approach, though; no exercise progression throughout the training period was provided.

However, as no previous studies have measured CEE in specific contraction velocities or exercise modes, it felt logical to start with a nonprogressive standard exercise for first establishing its effectiveness in ACL patients.

Finally, we did not determine the long-term effects of CEE following the ACL reconstruction. Thus, further research is required on this concept.

Conclusion

This study demonstrated that CEE used as supplementary to the ACL traditional rehabilitation program in the early stages of reconstruction improves quadriceps muscle strength deficit.

CEE at the frequencies of 3 or 5 days per week significantly minimized QD compared with a control group which did not receive CEE following the ACL reconstruction. Further research should be conducted to investigate the long-term effects of CE in ACL reconstruction rehabilitation management.

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